

## BTEV - A DEDICATED B EXPERIMENT AT THE TEVATRON

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### ABSTRACT

BTeV is a dedicated b-physics experiment that is expected to begin operation at the Fermilab Tevatron in 2008. BTeV is designed to take full advantage of the large production cross section of b particles (including  $B_S$ ) in high energy hadron collisions. A quick description of the BTeV spectrometer is given in this paper. Two unique aspects of BTeV, the pixel-based trigger and the high quality lead tungstate electromagnetic calorimeter, are described in slightly greater detail.

### 1 Overview

At the BTeV design luminosity of  $2 \times 10^{32} cm^{-2} s^{-1}$ , approximately  $4 \times 10^{11}$  b hadrons (including  $B_S$  and  $\Lambda_B$ ) will be produced every year at the Tevatron

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\* On behalf of the BTeV collaboration

collider. For comparison, approximately  $2 \times 10^8$  b's (no  $B_S$  or  $\Lambda_B$ ) will be produced per year at an  $e^+e^-$  factory operating at the  $\Upsilon(4s)$  with a luminosity of  $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . However, to take full advantage of this supply of B's, one needs a sophisticated trigger, excellent particle identification, excellent photon energy and position measurements, excellent vertex measurement, and excellent momentum measurement for charged particles. A central detector, especially one optimized for high  $p_T$  physics, can not satisfy these requirements; a dedicated experiment such as BTeV is required.

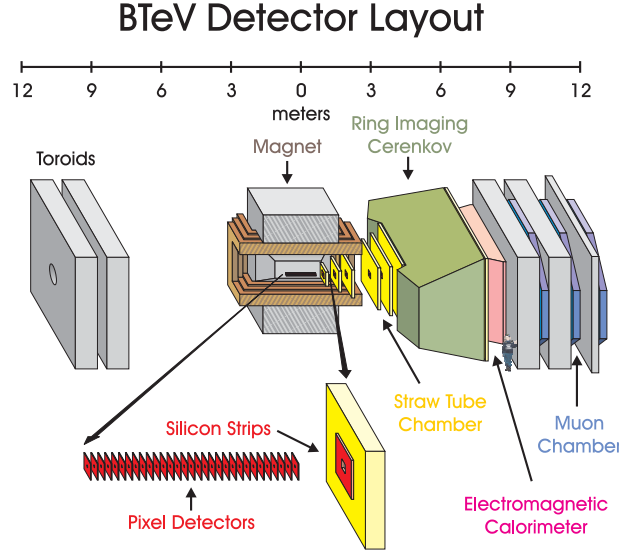


Figure 1: *The BTeV spectrometer.*

As shown in Fig. 1, BTeV is a forward magnetic spectrometer, with a large dipole magnet centered on the  $\bar{p}p$  interaction region. A pixel vertex detector is located in the magnet. The long tracking lever arm provides excellent momentum resolution for momenta between  $\sim 1$  and 100 GeV/c. The open layout allows the use of a ring imaging Cerenkov counter for excellent charged particle identification, and for a toroid muon spectrometer. Finally, the relatively small (compared to the LHC) range of particle momenta means that the charged particle tracking system can be short enough that an electromagnetic calorimeter can be constructed using scintillating crystals and still be affordable.

## 2 Pixel Vertex Detector and Trigger

The BTeV vertex detector will consist of a number of planar arrays of silicon pixel detectors mounted in the accelerator vacuum, transverse to the beam directions. Two movable carbon fiber half cylinders will support the planes. Silicon pixel detectors have been chosen because they provide excellent radiation tolerance <sup>1)</sup> and position resolution better than  $9\mu\text{m}$  at all angles of incidence <sup>2)</sup>, and most importantly, because they provide superb pattern recognition power.

An R&D program to develop a pixel readout chip optimized for the Tevatron was started at Fermilab in 1997, and is now nearing completion <sup>3)</sup>. The BTeV pixel readout chip has been designed using radiation tolerant layout techniques <sup>4)</sup> <sup>5)</sup> for implementation in either of two commercial processes - Taiwan Semiconductor Manufacturing Company  $0.25\mu\text{m}$  CMOS, or the  $0.25\mu\text{m}$  CMOS process available through CERN. The BTeV pixel size will be  $50\mu\text{m} \times 400\mu\text{m}$ . Each pixel chip will read out an array of  $22\text{ columns} \times 128\text{ rows}$  of pixels.

The most striking feature of BTeV is that the experiment will not use a trigger in the traditional sense of the word. All hit data from all detector elements will be digitized and read out *for every beam crossing*. At the design luminosity, data from the pixel vertex detector will be used to reconstruct tracks and interaction vertices for 15 million events per second (7.5 million crossings per second, with an average of 2 events per crossing). Data from the entire spectrometer will be buffered for up to *0.5 seconds* while the pixel data is reconstructed. The lowest level trigger will identify events containing reconstructable decays of charm and bottom particles <sup>6)</sup> using criteria of the type usually applied in offline analyses, while rejecting 99% of the minimum bias events. This is possible only because the extreme granularity and high efficiency of the pixel detector makes pattern recognition exceedingly simple. The first stages of track finding can be parallelized by looking for tracks only where they leave the beam region and where they leave the pixel detector. FPGA-based hardware will perform these operations. Subsequent stages of the trigger are performed by clusters of 2500 DSP's and 2000 conventional processors, each of which operates on data from a single beam crossing.

### 3 Lead Tungstate Calorimeter

The BTeV electromagnetic calorimeter will be made up of lead tungstate crystals. Lead tungstate, which has been developed for the CMS collaboration, was chosen because it is fast, radiation tolerant, and provides excellent position and energy resolution <sup>7)</sup>. BTeV will use photomultiplier tubes to measure the scintillation light produced in the crystals. This is possible since the BTeV calorimeter (unlike the CMS calorimeter) is not located in a magnetic field.

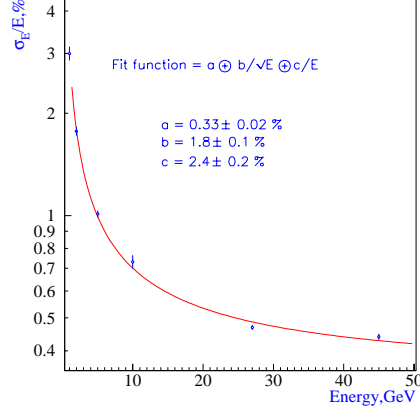


Figure 2: *Energy resolution obtained in beam tests of lead tungstate crystals.*

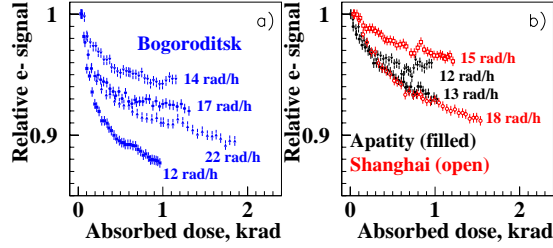


Figure 3: *Signal loss as a function of absorbed dose at different dose rates for lead tungstate crystals manufactured in Bogoroditsk (on the left) and in Apatity and Shanghai (on the right).*

In an ongoing series of beam tests at IHEP, Protvino, BTeV collaborators have verified the expected properties of lead tungstate <sup>8)</sup>. Significantly, good

results have been obtained with crystals made by a variety of vendors. Fig. 2 shows the energy resolution obtained. Both the constant term (0.33%) and the stochastic term ( $\frac{1.8\%}{\sqrt{E}}$ ) agree with Monte Carlo simulations. The  $\frac{1}{E}$  term in the fitting function reflects the uncertainty in the electron beam energy. Fig. 3 shows the measured loss of signal as a function of absorbed dose for a number of different crystals irradiated at rates between 12 rad/hour and 22 rad/hour. Continuous calibration will be very important for the BTeV calorimeter since the light output is a strong function of dose rate and (as can be seen in the figure) there are large crystal-to-crystal differences.

Table 1: *Summary of Physics Reach of BTeV in  $10^7$  sec*

Decay Mode	$BR$ ( $\times 10^{-6}$ )	Events	S/B	Parameter	Error (or Value)
$B^0 \rightarrow \pi^+ \pi^-$	4.5	14,600	3	asymmetry	0.030
$B_s \rightarrow D_s K$	300	7500	7	$\gamma$	$8^\circ$
$B^0 \rightarrow J/\psi K_s, \psi \rightarrow l^+ l^-$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \rightarrow D_s \pi^-$	3000	59,000	3	$x_s$	(75)
$B^- \rightarrow D^0(K^+ \pi^-) K^-$	0.17	170	1	$\gamma$	$13^\circ$
$B^- \rightarrow D^0(K^+ K^-) K^-$	1.1	1000	10		
$B^- \rightarrow K_s \pi^-$	12.1	4600	1		$< 4^\circ$
$B^- \rightarrow K^- \pi^0$	18.8	62000	20	$\gamma$	+ theory errors
$B^0 \rightarrow \rho^+ \pi^-$	28	5400	4		
$B^0 \rightarrow \rho^0 \pi^0$	5	780	0.3	$\alpha$	$\sim 4^\circ$
$B_s \rightarrow J/\psi \eta$	330	2800	15		
$B_s \rightarrow J/\psi \eta'$	670	9800	30	$\sin(2\chi)$	0.024

#### 4 Conclusion

BTeV is designed to make precise measurements of standard model parameters in the b and c quark systems, and to perform an exhaustive search for physics beyond the standard model. Simulations have been done using GEANT3 to determine the sensitivity of BTeV to a large number of b decays. Table 1, which is taken from a recent review of the BTeV physics reach<sup>9)</sup>, summarizes the expected BTeV sensitivity in a variety of modes important for measuring parameters of the CKM quark mixing matrix. BTeV will also be very sensitive

to a number of rare decays. For example, the annual yield of  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$  is expected to be over 2500 events, when cuts are employed to yield a signal to background ratio of 11/1. Finally, the combination of a very capable spectrometer, including a high quality electromagnetic calorimeter, and a sophisticated vertex trigger, will give BTeV the flexibility to make precise measurements of the full range of b decays, not simply those decays thought to be most important today.

## References

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